

Claims

1. A method of separating a polymer from a biomass containing the polymer, the method comprising:
  - contacting the biomass with a solvent system, including a solvent for the polymer and a precipitant for the polymer, to provide a residual biomass and a solution that includes the polymer, the solvent for the polymer and the precipitant for the polymer; and
  - applying a centrifugal force to the solution and residual biomass to separate at least some of the solution from the residual biomass.
2. The method of claim 1, wherein the solvent for the polymer has a density of less than about 0.95 kilograms per liter.
3. The method of claim 1, wherein the solvent for the polymer is non-halogenated.
4. The method of claim 1, wherein the solvent for the polymer has a solubility in water of less than about one percent.
5. The method of claim 1, wherein the solvent for the polymer is substantially non-hydrolyzable.
6. The method of claim 1, wherein the solvent for the polymer has a logK value relative to water at 100°C of at least about 1.5.
7. The method of claim 1, wherein the solvent that has a boiling point greater than 100°C.
8. The method of claim 1, wherein the solvent for the polymer is selected from the group consisting of ketones, esters and alcohols.

9. The method of claim 1, wherein the solvent for the polymer is selected from the group consisting of MIBK, butyl acetate, cyclo-hexanone and combinations thereof.
10. The method of claim 1, wherein the precipitant for the polymer dissolves less than about 0.2% of the polymer at room temperature.
11. The method of claim 1, wherein the solvent for the polymer and the precipitant for the polymer have a relative volatility of at least about two at an equimolar bubble point for the solvent for the polymer and the precipitant for the polymer.
12. The method of claim 1, wherein the solvent for the polymer and the precipitant for the polymer do not form an azeotrope.
13. The method of claim 1, wherein the precipitant comprises at least one alkane.
14. The method of claim 1, wherein the solution comprises at most about 25% by volume of the precipitant for the polymer.
15. The method of claim 1, wherein the solution has a polymer concentration of at least about two percent.
16. The method of claim 1, wherein the solution has a viscosity of at most about 100 centipoise.
17. The method of claim 1, wherein the biomass containing the polymer is of microbial origin and has a polymer content of at least about 50 weight percent.
18. The method of claim 1, wherein the biomass containing the polymer is of plant origin and has a polymer content of less than about 50 weight percent.

19. The method of claim 1, wherein the biomass containing the polymer comprises cells that contain the polymer.
20. The method of claim 1, further comprising removing at least some of the polymer from the solution.
21. The method of claim 20, further comprising extruding the removed polymer to dry and pelletize the polymer.
22. The method of claim 20, wherein removing the polymer from the solution does not include exposing the solution to hot water.
23. The method of claim 20, wherein removing the polymer from the solution includes adding a second precipitant for the polymer to the solution.
24. The method of claim 23, wherein the first and second precipitants for the polymer are the same.
25. The method of claim 20, further comprising evaporating a portion of the solution before removing at least some of the polymer from the solution.
26. The method of claim 1, further comprising, after applying the centrifugal force to the solution, adding a volume of a second precipitant for the polymer to remove at least some of the polymer from the solution,  
wherein the volume of the second precipitant is less than about two parts relative to the volume of the solvent system.
27. The method of claim 1, wherein the polymer comprises a PHA.
28. A method of separating a polymer from biomass containing the polymer, the method comprising:

contacting the biomass with a solvent system to provide a residual biomass and a solution including the polymer and the solvent system;

adding a precipitant for the polymer to the solution; and

separating at least some of the solution from the residual biomass after adding the precipitant for the polymer.

29. The method of claim 28, wherein the solvent system comprises a solvent for the polymer that has a density of less than about 0.95 kilograms per liter.

30. The method of claim 28, wherein the solvent system comprises a non-halogenated solvent for the polymer.

31. The method of claim 28, wherein the solvent system comprises a solvent for the polymer that has a solubility in water of less than about one percent.

32. The method of claim 28, wherein the solvent system comprises a solvent for the polymer that is substantially non-hydrolyzable.

33. The method of claim 28, wherein the solvent system comprises a solvent for the polymer that has a logK value relative to water at 100°C of at least about 1.5.

34. The method of claim 28, wherein the solvent system comprises a solvent for the polymer that has a boiling point greater than 100°C.

35. The method of claim 28, wherein the solvent system comprises at least one solvent selected from the group consisting of ketones, esters and alcohols.

36. The method of claim 28, wherein the solvent system comprises at least one solvent selected from the group consisting of MIBK, butyl acetate, cyclo-hexanone and combinations thereof.

37. The method of claim 28, wherein solvent system comprises a precipitant for the polymer that dissolves less than about 0.2% of the polymer at room temperature.
38. The method of claim 28, wherein the solvent system comprises a solvent for the polymer and a precipitant for the polymer, and the solvent for the polymer and the precipitant for the polymer have a relative volatility of at least about two at an equimolar bubble point for the solvent for the polymer and the precipitant for the polymer.
39. The method of claim 28, wherein the solvent system comprises a solvent for the polymer and a precipitant for the polymer, and the solvent for the polymer and the precipitant for the polymer do not form an azeotrope.
40. The method of claim 28, wherein the solvent system comprises a precipitant for the polymer that comprises an alkane.
41. The method of claim 28, wherein the solution has a polymer concentration of at least about two percent.
42. The method of claim 28, wherein the solution has a viscosity of at most about 100 centipoise.
43. The method of claim 28, wherein the biomass containing the polymer is of microbial origin and has a polymer content of at least about 50 weight percent.
44. The method of claim 28, wherein the biomass containing the polymer is of plant origin and has a polymer content of less than about 50 weight percent.
45. The method of claim 28, wherein the biomass containing the polymer comprises cells that contain the polymer.

46. The method of claim 28, further comprising removing at least a portion of the polymer from the solution, wherein removing the polymer does not include exposing the solution to hot water.
47. The method of claim 28, wherein separating at least some of the solution from the residual biomass includes applying a centrifugal force to the solution and the residual biomass.
48. The method of claim 28, further comprising evaporating a portion of the solution before adding a precipitant for the polymer to the solution to remove at least some of the polymer from the solvent system.
49. The method of claim 28, further comprising, after separating, adding a volume of a second precipitant for the polymer to remove at least some of the polymer from the solution,  
wherein the volume of the second precipitant is less than about two parts relative to the volume of the solvent system.
50. The method of claim 28, further comprising:  
removing at least a portion of the polymer from the solution; and  
extruding the removed polymer to dry and pelletize the polymer.
51. The method of claim 28, wherein the polymer comprises a PHA.
52. A method of separating a polymer from biomass containing the polymer, the method comprising:  
contacting the biomass with a solvent system to provide a residual biomass and a solution including the polymer and the solvent system, the solution having a polymer concentration of at least about two percent and a viscosity of at most about 100 centipoise; and  
separating at least some of the solution from the residual biomass.

53. The method of claim 52, wherein the solvent system comprises a solvent for the polymer that has a density of less than about 0.95 kilograms per liter.
54. The method of claim 52, wherein the solvent system comprises a non-halogenated solvent for the polymer.
55. The method of claim 52, wherein the solvent system comprises a solvent for the polymer that has a solubility in water of less than about one percent.
56. The method of claim 52, wherein the solvent system comprises a solvent for the polymer that is substantially non-hydrolyzable.
57. The method of claim 52, wherein the solvent system comprises a solvent for the polymer that has a logK value relative to water at 100°C of at least about 1.5.
58. The method of claim 52, wherein the solvent system comprises a solvent for the polymer that has a boiling point greater than 100°C.
59. The method of claim 52, wherein the solvent system comprises at least one solvent selected from the group consisting of ketones, esters and alcohols.
60. The method of claim 52, wherein the solvent system comprises at least one solvent selected from the group consisting of MIBK, butyl acetate, cyclo-hexanone and combinations thereof.
61. The method of claim 52, wherein the solvent system comprises a precipitant for the polymer that dissolves less than about 0.2% of the polymer at room temperature.
62. The method of claim 52, wherein the solvent system comprises a solvent for the polymer and a precipitant for the polymer, the solvent for the polymer and the precipitant

for the polymer having a relative volatility of at least about two at an equimolar bubble point for the solvent for the polymer and the precipitant for the polymer.

63. The method of claim 52, wherein the solvent system comprises a solvent for the polymer and a precipitant for the polymer, and the solvent for the polymer and the precipitant for the polymer do not form an azeotrope.

64. The method of claim 52, wherein the solvent system comprises a precipitant for the polymer that comprises an alkane.

65. The method of claim 52, wherein the biomass containing the polymer is of microbial origin and has a polymer content of at least about 50 weight percent.

66. The method of claim 52, wherein the biomass containing the polymer is of plant origin and has a polymer content of less than about 50 weight percent.

67. The method of claim 52, wherein the biomass containing the polymer comprises cells that contain the polymer.

68. The method of claim 52, further comprising removing at least some of the polymer from the solution.

69. The method of claim 68, further comprising extruding the removed polymer to dry and pelletize the polymer.

70. The method of claim 68, wherein removing the polymer from the solution does not include exposing the solution to hot water.

71. The method of claim 68, wherein removing the polymer from the solution includes adding a precipitant for the polymer to the solution.

72. The method of claim 68, further comprising evaporating a portion of the solution before removing at least some of the polymer from the solution.

73. The method of claim 52, wherein separating at least some of the solution from the residual biomass includes applying a centrifugal force to the solution and the residual biomass.

74. The method of claim 52, wherein the polymer comprises a PHA.

75. A method of separating a polymer from a biomass containing the polymer and biomass impurities, the method comprising:

contacting the biomass with at least one alkane to remove at least some of the biomass impurities from the biomass containing the polymer and the biomass impurities, thereby providing a purified biomass containing the polymer; and

contacting the purified biomass with a solvent system to provide a residual biomass and a solution including the polymer and the solvent for the polymer.

76. The method of claim 75, further comprising separating at least some of the solution from the residual biomass, and adding a precipitant for the polymer to the solution to remove at least some of the polymer from the solvent system.

77. The method of claim 75, wherein the solvent system comprises a solvent for the polymer that has a density of less than about 0.95 kilograms per liter.

78. The method of claim 75, wherein the solvent system comprises a non-halogenated solvent for the polymer.

79. The method of claim 75, wherein the solvent system comprises a solvent for the polymer that has a solubility in water of less than about one percent.

80. The method of claim 75, wherein the solvent system comprises a solvent for the polymer that is substantially non-hydrolyzable.
81. The method of claim 75, wherein the solvent system comprises a solvent for the polymer that has a logK value relative to water at 100°C of at least about 1.5.
82. The method of claim 75, wherein the solvent system comprises a solvent for the polymer that has a boiling point greater than 100°C.
83. The method of claim 75, wherein the solvent system comprises at least one solvent selected from the group consisting of ketones, esters and alcohols.
84. The method of claim 75, wherein the solvent system comprises at least one solvent selected from the group consisting of MIBK, butyl acetate, cyclo-hexanone and combinations thereof.
85. The method of claim 75, wherein the solvent system comprises a precipitant for the polymer that dissolves less than about 0.2% of the polymer at room temperature.
86. The method of claim 75, wherein the solvent system comprises a solvent for the polymer and a precipitant for the polymer, and the solvent for the polymer and the precipitant for the polymer have a relative volatility of at least about two at an equimolar bubble point for the solvent for the polymer and the precipitant for the polymer.
87. The method of claim 75, wherein the solvent system comprises a solvent for the polymer and a precipitant for the polymer, and the solvent for the polymer and the precipitant for the polymer do not form an azeotrope.
88. The method of claim 75, wherein the alkane is hexane, heptane or an isoalkane.

89. The method of claim 75, wherein the solution has a polymer concentration of at least about two percent.
90. The method of claim 75, wherein the solution has a viscosity of at most about 100 centipoise.
91. The method of claim 75, wherein the biomass containing the polymer is of microbial origin and has a polymer content of at least about 50 weight percent.
92. The method of claim 75, wherein the biomass containing the polymer is of plant origin and has a polymer content of less than about 50 weight percent.
93. The method of claim 75, wherein the biomass containing the polymer comprises cells that contain the polymer.
94. The method of claim 75, removing at least a portion of the polymer from the solution, wherein removing the polymer does not include exposing the solution to hot water.
95. The method of claim 75, wherein separating at least some of the solution from the residual biomass includes applying a centrifugal force to the solution and the residual biomass.
96. The method of claim 75, further comprising evaporating a portion of the solution before adding a precipitant for the polymer to the solution to remove at least some of the polymer from the solvent system.
97. The method of claim 75, further comprising:  
removing at least a portion of the polymer from the solution; and  
extruding the removed polymer to dry and pelletize the polymer.

98. The method of claim 75, wherein the polymer comprises a PHA.
99. A method of separating a polymer from a biomass containing the polymer, the method comprising:  
contacting the biomass with a solvent system under countercurrent flow conditions.
100. The method of claim 99, further comprising forming a PHA phase and a residual biomass phase,  
wherein a ratio of volume present of the solvent system present in the PHA phase to volume of the solvent system contacted with the biomass is at least about 0.8.
101. The method of claim 99, further comprising forming a PHA phase and a residual biomass phase,  
wherein a ratio of volume of the solvent system present in the residual biomass phase to volume of the solvent system contacted with the biomass is at most about 0.2.
102. The method of claims 99, wherein the method is a one-stage method.
103. The method of claim 99, wherein the method is a multi-stage method.
104. The method of claim 99, wherein the countercurrent flow conditions include a pressure of at least about 65 psig.
105. A method of separating a polymer from a biomass containing the polymer, the method comprising:  
contacting the biomass with a solvent system using a one-stage process that forms a PHA phase and a residual biomass phase,  
wherein a ratio of volume of the solvent system present in the PHA phase to volume of the solvent system contacted with the biomass is at least about 0.8.

106. The method of claim 105, wherein a ratio of volume of the solvent system present in the residual biomass phase to volume of the solvent system contacted with the biomass is at most about 0.2.

107. A method of separating a polymer from a biomass containing the polymer, the method comprising:

contacting the biomass with a solvent system using a one-stage process that forms a PHA phase and a residual biomass phase,

wherein a ratio of volume of the solvent system present in the residual biomass phase to volume of the solvent system contacted with the biomass is at most about 0.2.

108. The method of claim 1, wherein the solvent system is contacted with the biomass under countercurrent flow conditions.

109. The method of claim 108, wherein the method is a one-stage method.

110. The method of claim 108, wherein the method is a multi-stage method.

111. The method of claim 108, wherein the countercurrent conditions include a pressure of at least about 65 psig.

112. The method of any of claim 28, wherein the solvent system is contacted with the biomass under countercurrent flow conditions.

113. The method of claim 112, wherein the method is a one-stage method.

114. The method of claim 112, wherein the method is a multi-stage method.

115. The method of claim 112, wherein the countercurrent conditions include a pressure of at least about 65 psig.

116. The method of claim 52, wherein the solvent system is contacted with the biomass under countercurrent flow conditions.
117. The method of claim 116, wherein the method is a one-stage method.
118. The method of claim 116, wherein the method is a multi-stage method.
119. The method of claim 116, wherein the countercurrent conditions include a pressure of at least about 65 psig.
120. The method of claim 75, wherein the at least one alkane is contacted with the biomass under countercurrent flow conditions.
121. The method of claim 120, wherein the method is a one-stage method.
122. The method of claim 120, wherein the method is a multi-stage method.
123. The method of claim 120, wherein the countercurrent conditions include a pressure of at least about 65 psig.
124. The method of claim 99, wherein the at least one alkane is contacted with the biomass under countercurrent flow conditions.
125. The method of claim 124, wherein the method is a one-stage method.
126. The method of claim 124, wherein the method is a multi-stage method.
127. The method of claim 124, wherein the countercurrent conditions include a pressure of at least about 65 psig.